

MIL-H-8501B: APPLICATION TO SHIPBOARD TERMINAL OPERATIONS

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ABSTRACT

The philosophy and structure of the proposed U.S. Military Specification for Handling Qualities Requirements for Military Rotorcraft, MIL-H-8501B, are presented with emphasis on shipboard terminal operations. The impact of current and future naval operational requirements on the selection of appropriate combinations of basic vehicle dynamics and usable cue environment are identified. An example "walk through" of MIL-H-8501B is conducted from task identification to determination of stability and control requirements. For selected basic vehicle dynamics, criteria as a function of input/response magnitude are presented. Additionally, rotorcraft design development implications are discussed.

UCE - Usable Cue Environment. The cue environment defined by the mission visual environment including both Outside world Visual Conditions (OVC) and the available displays and vision aids.

VMC - Visual Meteorological Conditions.

IMC - Instrument Meteorological Conditions. Meteorological conditions which require operation of the rotorcraft solely with reference to flight instruments. Occurs when rotorcraft is clear of all obstacles.

IFR - Instrument Flight Rules. Standard procedures which generally apply in IMC.

Near Earth Operations - Operations sufficiently close to the ground or fixed objects on the ground, or near water and in the vicinity of ships, etc., that near-field navigation is primarily accomplished with reference to outside objects.

Response-Type - The basic shape of the response in terms of dynamic parameters.

NOMENCLATURE

OFE - Operational Flight Envelope. The boundaries within which the rotorcraft must be capable of operating in order to accomplish the mission.

SFE - Service Flight Envelope. Boundaries defined by aircraft limits as distinguished from mission requirements.

MTE - Mission-Task-Element. An element of a mission that can be treated as a handling qualities task.

H/LS - Hover/Low Speed. Ground speeds from 0 to 45 knots.

F/F - Forward Flight. Ground speeds 45 knots and above.

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1.0 INTRODUCTION

The proposed U.S. Military Specification for Handling Qualities Requirements for Military Rotorcraft, MIL-H-8501B (reference 1), represents a radical new approach to the specification of air vehicle flying qualities. For the first time, flying qualities criteria are explicitly specified as a function of both flight task and usable cue environments. As a direct consequence, MIL-H-8501B has strong mission oriented design implications. Further, this flying qualities specification will have particular impact in the design of not only the airframe, rotor system and

flight control system, but also the displays and vision aids.

Shipboard recovery is one of the more difficult flight tasks required of a pilot and his aircraft. This flight task even in the best environmental conditions is demanding. Mission requirements, however, force poor weather operations where launch and recovery in poor visual conditions and high sea states are routine. Under these conditions, the aircraft's flying qualities are a function of not only the vehicle's stability and control characteristics, but also the visual cues available to the pilot.

This paper presents the philosophy, structure and criteria of MIL-H-8501B with emphasis on shipboard terminal operations. The impact of current and future naval operational requirements on the selection of appropriate combinations of basic vehicle dynamics and usable cue environment are identified. An example "walk through" of MIL-H-8501B is conducted from task identification to determination of stability and control requirements. For selected basic vehicle dynamics, criteria as a function of input/response magnitude are presented. Additionally, rotorcraft design implications are discussed.

2.0 MIL-H-8501B BACKGROUND

It has long been recognized that the current U.S. military specification of General Requirements for Helicopter Flying and Ground Handling Qualities, MIL-H-8501A (reference 2), is inadequate for application to modern rotorcraft. Several handling qualities specialists (references 3 through 6) have identified the inadequacies. Specific areas of concern lie with MIL-H-8501A's inability to specify technically sufficient requirements for performance of demanding tasks in severe environments, employment of high control augmentation systems, and the use of advanced displays and vision aids. Due to the combination of current day mission requirements and current rotorcraft design methodologies, MIL-H-8501A simply can no longer ensure satisfactory flying qualities.

The development of several recent rotorcraft weapon systems, including the U.S. Navy Light Airborne Multipurpose System (LAMPS) Mk III SH-60B, have required the use of flying qualities type specifications (reference 7). These type specifications, while incorporating several MIL-H-8501A requirements,

have utilized many new requirements which are primarily mission performance oriented.

Beginning in 1982 the U.S. Army initiated a three phased effort to develop mission oriented handling qualities requirements for military rotorcraft. The objectives of the phase I effort were: the development of a new specification structure, the incorporation of existing criteria and data, the definition of critical gaps in the data base, and the formulation of a draft specification and background information and users guide (BIUG). Two major and distinctly different approaches evolved and were documented in references 8, 9 and 10.

The objectives of phase II were to fill in the critical data and criteria gaps and generally refine the specification. Continuing in 1984 with phase II, utilizing the approach of references 9 and 10, the U.S. Army shifted the development of the specification from general requirements to LHX oriented requirements. Once this effort was complete, they again sought, with the aid of the Navy and industry, to develop a generic specification. This was accomplished by generalizing the LH specification and BIUG for application to all types of modern rotorcraft. In this phase investigations were performed to generate data to fill the numerous data gaps. Through the last part of phase II, several government and industry reviews of the specification and BIUG (reference 11) were conducted in order to refine the criteria.

While currently in phase III, tri-service (Army, Navy, Air Force) review, adoption of the new specification is expected soon.

Through demonstration of MIL-H-8501B applicability to aircraft/ship operations, this paper represents part of the continuing effort by the U.S. Navy to assist in maturing the proposed specification.

3.0 MIL-H-8501B PHILOSOPHY

MIL-H-8501B incorporates several fundamental concepts in its philosophy. The first of these concepts is the use of the Cooper-Harper Handling Qualities Rating (HQR) Scale (reference 12) and the associated handling qualities levels, defined in Figure 1, as a metric to quantify the acceptability of a vehicles flying qualities.

Many MIL-H-8501B criterion boundaries are based on both simulation and flight test HQR data. The primary use of the scale is to correlate pilot ratings

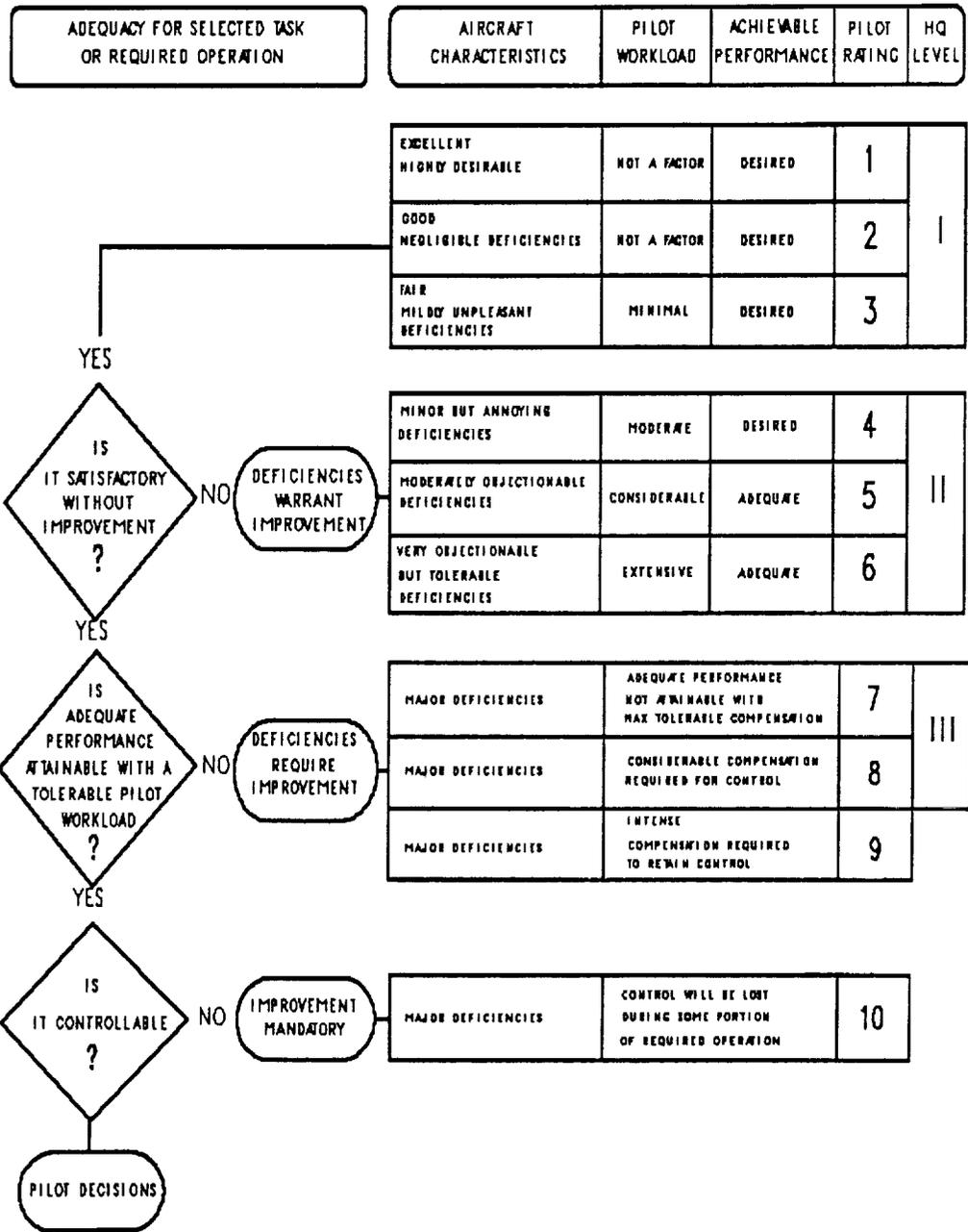


Figure 1 Handling Qualities Rating Scale.

from handling qualities experiments and compliance tests conducted in simulation or flight with parameters used in the specification. The requirements specify that the minimum handling qualities must be Level 1 within the OFE and Level 2

within the SFE. Further, the specification allows for degradation of flying qualities due to failures. One of the two methods describing the allowable degradations is given in Table 1.

Table 1 Levels For Rotorcraft Failure States

Probability of Encountering	Within Operational Flight Envelope	Within service Flight Envelope
Level 2 after failure	< 2.5 x 10 ⁻³ per flight hr	
Level 3 after failure	< 2.5 x 10 ⁻⁵ per flight hr	< 2.5 x 10 ⁻³ per flight hr

The U.S. Navy uses two other scales to determine the general acceptability of a helicopter - the Dynamic Interface Pilot Rating Scale (Table 2) (references 13 and 14), which is specifically used in the shipboard launch and recovery environment, and the Deficiencies Scale (Table 3) (reference 15). Neither scale, however, specifically addresses the acceptability of the vehicle's handling qualities. The former quantifies relative degrees of pilot effort required for conducting helicopter launches and recoveries during shipboard operations. The latter, quantifies the severity of aircraft deficiencies with regard to their impact on the vehicles ability to perform it's intended mission.

The second fundamental concept of MIL-H-8501B is the specification of a minimum required response type as a function of the Mission Task Element (MTE) and Usable Cue Environment (UCE). The intent of this concept is to establish a methodology which allows the specification to relate required vehicle dynamics to mission requirements and the operational visual environment. Implicit in this concept is a "trade-off" relationship between response type, displays and vision aids, and task difficulty. Essentially, as task difficulty increases, stability and control augmentation should be increased. As visual conditions degrade, stability and control augmentation or visual augmentation should be increased.

The complete procedure for determining the UCE is given in Section 3.2.2.1 of reference 1. In summary, the UCE is determined by taking an existing rotorcraft with a rate command response type and exhibiting Level 1 flying qualities in clear day negligible turbulence conditions, installing all the displays and vision aids proposed for use in the production rotorcraft, and flying test maneuvers in the actual operational environment. Three pilots perform this evaluation, quantifying the useable cues using the rating scale shown in Figures 2a and 2b. The test maneuvers consist of a basic set of MTE's including: hover, vertical landing, pirouette,

acceleration and deceleration, sidestep, bob up and down.

Table 2 Dynamic Interface Pilot Rating Scale

Defining relative degrees of pilot effort required for conducting helicopter launches and recoveries during shipboard operations.

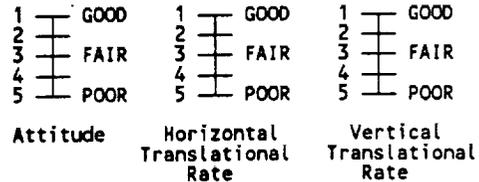
PRS	Pilot Effort	Description
1	Slight	No problems; minimal pilot effort required.
2	Moderate	Consistently safe launch and recovery operations under these conditions. These points define the fleet limits recommended by NAVAIRTESTCEN.
3	Maximum	Landings and takeoffs successfully conducted through maximum effort of experienced test pilots under controlled conditions. These evolutions could not be consistently repeated by fleet pilots under operational conditions. Loss of aircraft or ship system is likely to raise pilot effort beyond capabilities of average fleet pilot.
4	Unsat	Pilot effort and/or controllability reach critical levels, and repeated safe landings and takeoffs by experienced test pilots are not probable, even under controlled test conditions.

Both the minimum required control system types and the specific trade-off relationships with displays and vision aids for hover and low speed near earth operations are defined in Table 1(3.2) of reference 1. Similarly, Table 2(3.2) of reference 1 define these requirements/relationships for forward flight.

The third concept is the use of a combination of specific quantitative requirements, the "Section 3" criteria, and separate but equally important flight test requirements, the "Section 4" criteria, to completely determine the vehicle's handling qualities. The Section 3 criteria are a combination of frequency and time domain requirements to quantitatively define the required vehicle dynamics. The flight test requirements are included as an independent assessment of the overall vehicle handling qualities. The flight test requirements compliment the quantitative requirements and are intended to "smoke out" handling qualities deficiencies which may be undetermined by the Section 3 criteria. Section 4 is less comprehensive then Section 3 and is not intended as a substitute for Section 3.

Table 3 Definition of Deficiencies

<p><u>Part I</u> indicates a deficiency, the correction of which is necessary because it adversely affects:</p> <p>a. Airworthiness of the aircraft.</p> <p>b. The ability of the aircraft to accomplish its primary or secondary mission.</p> <p>c. The effectiveness of the crew as an essential subsystem.</p> <p>d. The safety of the crew or the integrity of an essential subsystem. In this regard, a real likelihood of injury or damage must exist. Remote possibilities or unlikely sequences of events shall not be used as a basis for safety items.</p>
<p><u>Part II</u> indicates a deficiency of lesser severity than a Part I which does not substantially reduce the ability of the aircraft to accomplish its primary or secondary mission, but the correction of which will result in significant improvement in the effectiveness, maintainability, or safety of the aircraft.</p>
<p><u>Part III</u> indicates a deficiency that appears too impractical or costly to correct in this model but which should be avoided in future designs. Included are violations of specifications for use by the contract negotiator in final settlement of the contract.</p>

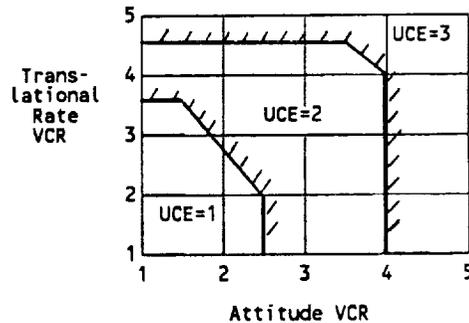


DEFINITION OF CUES

X = Pitch or roll attitude and lateral, longitudinal or vertical translational rate.

- Good X Cues: Can make aggressive and precise X Corrections with confidence and precision is good.
- Fair X Cues: Can make limited X corrections with confidence and precision is only fair.
- Poor X Cues: Only small and gentle corrections in X are possible and consistent precision is not attainable.

a) Visual Cue Rating (VCR) Scale



b) Definition of Usable Cue Environment (UCE) Rating

The U.S. Navy currently uses developmental and operational testing (DT and OT respectively) for evaluation of a new or modified weapon system (reference 15). Bearing no relationship to the flight test requirements of MIL-H-8501B Section 4, these tests are performed to evaluate the airworthiness of the aircraft and the ability of the aircraft to accomplish its primary or secondary mission. DT and OT, by design, evaluate the aircraft as a weapon system, and as such, involve a myriad of considerations. Handling qualities evaluations are typically conducted during and after full scale engineering development. Often faulty or non-optimum design characteristics are already part of the completed system and are difficult and/or expensive to fix.

Figure 2 UCE Determination

Section 4.0 criteria of the proposed specification and the DT and OT evaluations seek to achieve related but distinctly different results. Therefore, there remains a necessity for both.

4.0 MIL-H-8501B STRUCTURE

The general structure of the proposed specification is illustrated in Figure 3. The Scope, Compliance, and Definitions blocks correspond to Sections 1 and 2,

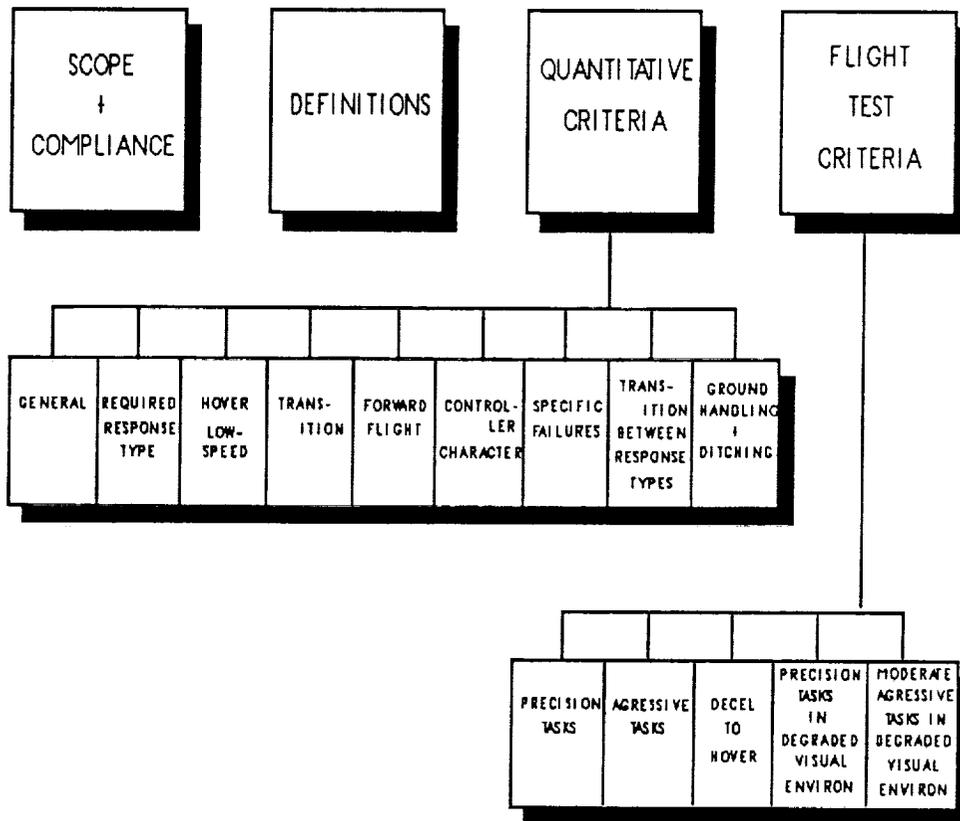


Figure 3 Specification Structure.

and the quantitative and flight test blocks to Sections 3 and 4, respectively.

5.0 MIL-H-8501B METHODOLOGY

The process by which the user and designer apply the specification is illustrated by Figure 4. Essentially, the user must first define the mission and mission environments. This includes definition of the mission task elements, degraded visual environments, requirements for divided attention, maximum winds in which the aircraft is expected to operate, and any

other mission oriented requirements. From this the designer can determine the flight envelopes, usable cue environments, and required response types. Using the Section 3 criteria the designer can then determine the required dynamic characteristics for a given level of handling qualities. Trade-offs between visual and control augmentation can be made using the guidance provided in Section 3. These design trade-offs would be motivated by both the user's and manufacturer's design philosophies. With the application of MIL-H-8501B, handling qualities requirements will directly effect many areas of the

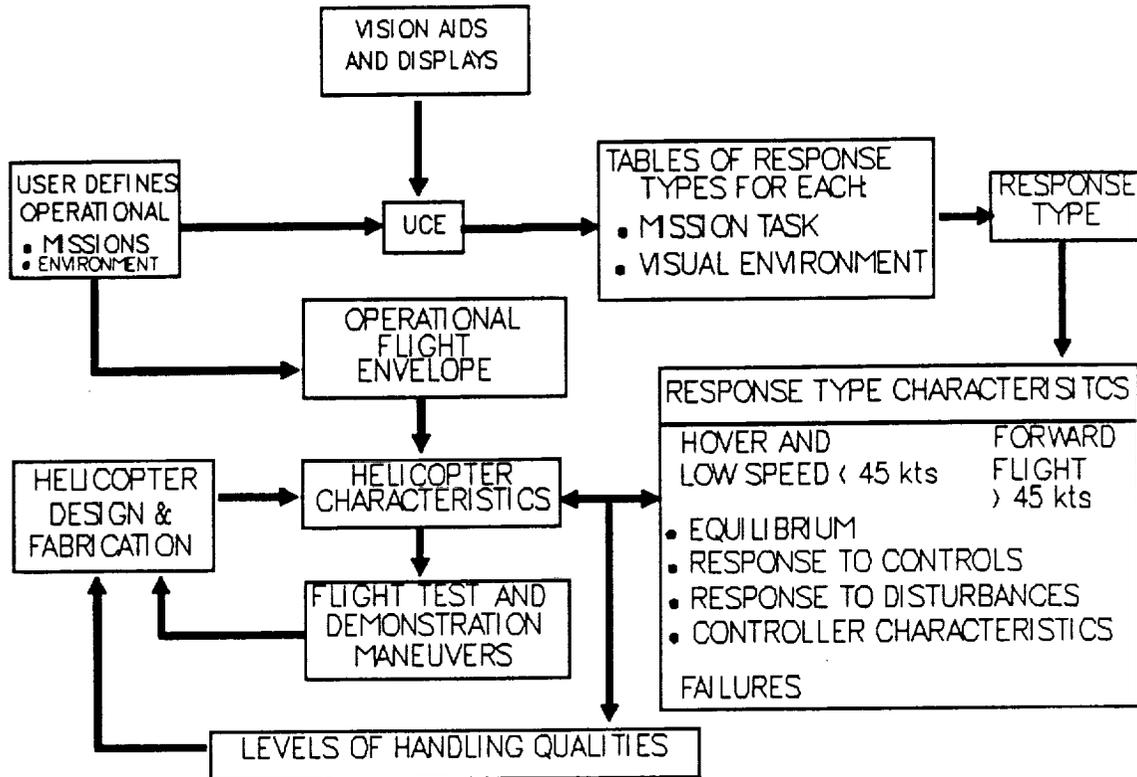


Figure 4 Schematic for Handling Qualities Specification and Assessment.

design, including the airframe, rotor system, control system, cockpit layout, and avionics, and, therefore must be considered early in the design process. Due to the timing of this process, handling qualities take on a renewed importance.

6.0 NAVAL OPERATIONS

6.1 Mission and Vehicles

The U.S. Navy's overall mission is to control the seas in wartime and project military power ashore. The tasks required to accomplish this mission include, among others, the acquisition and distribution of intelligence, surface ship and submarine attack, amphibious assault and deployment, and defense of related assets ashore in friendly or enemy territory. In support of these tasks, rotary wing aircraft operate from a wide variety of U.S. Navy ships ranging from the large deck carriers (CV) to smaller deck carriers for amphibious assault operations (LHA, LHD, LPH), to much smaller aviation capable ships such as

destroyers (DD) and frigates (FFG). The associated missions include airborne mine countermeasures (AMCM), antisubmarine warfare (ASW), antiship surveillance and targeting (ASST), vertical on board delivery (VOD), naval gunfire support (NVG), amphibious assault, amphibious reconnaissance, and search and rescue (SAR).

The U.S. Navy currently operates several different multi-role rotorcraft. Among these are the SH-3D/H Sea King for shore and ship based ASW, logistical support and SAR, the SH-2F Sea Sprite LAMPS Mark I for ASW and ASST, the SH-60B Seahawk LAMPS Mark III for ASW and ASST, and the RH-53D Sea Stallion for ship or shore based AMCM. Vertical replenishment (VERTREP), medical evacuation (MEDEVAC) and passenger transfer operations are common alternate roles. Other rotorcraft include the AH-1W Cobra, UH-1N Iroquois, CH-46 Sea Night and CH-53E Sea Stallion.

Currently all naval rotorcraft are equipped with standard electro-mechanical instruments, e.g. clocks, radar and barometric altimeters, airspeed, vertical velocity, attitude, hover and torque indicators. There is extremely limited precision guidance instrumentation and no operational head-up or helmet-mounted displays.

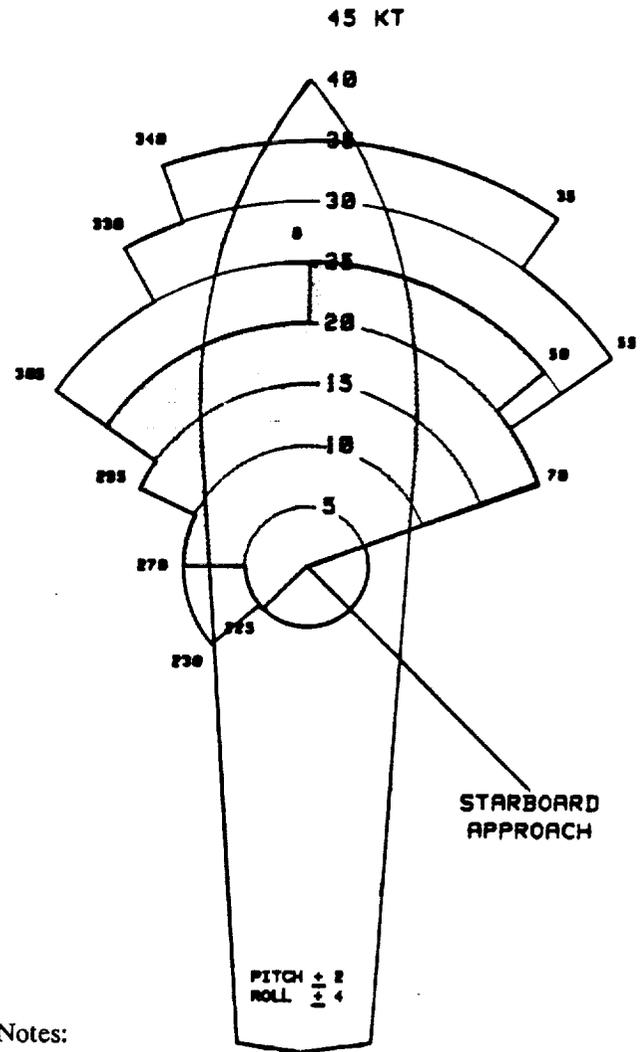
6.2 Impact of Environmental Conditions

Even though it is desirable to have an all-weather capability, flight operations are often limited by environmental conditions. Reference 16, the Naval Air Training and Operating Procedures Standardization (NATOPS) General Flight Operating Instructions and the vehicle specific NATOPS manuals provide guidelines on, among other issues, the operational limitations related to environmental conditions. Further, these guidelines are often tailored by the organizational commanders of shore based operational commands, e.g. reference 17 and 18. For many shipboard operations, the vehicle NATOPS and the specific ship's standard operating procedures (SOP) provide the operational pilots with the necessary information on the environmental conditions within which they can operate.

The factors influencing helicopter flight operations include weather (sea state, winds, visibility and ceiling) at takeoff and forecasted for time of arrival, the pilot's rating, and the vehicle's rating (with regard to ability and qualification to operate in degraded visibility). Helicopter operations are not normally conducted with a ceiling below 500 feet and visibility less than 1 mile (reference 19). Moreover, recommended weather minimums for launching helicopters on SAR operations are 300 foot ceiling with 1 mile visibility.

Shipboard launch and recovery envelopes are limited by visibility, ship pitch and roll, physical obstructions, and ship airwake. All combine to make shipboard terminal operations hazardous. The compatibility of specific rotorcraft and ship combinations are determined by static interface tests to examine space and servicing issues and dynamic interface tests to determine operational flight envelope parameters. During the dynamic interface tests, aircraft performance and flying qualities are evaluated in the actual ship environment to establish the actual takeoff and landing limitations. Test results are published for operational use as launch/recovery envelopes expressed in terms of relative wind

direction and magnitude for specified levels of ship motion (references 20, 21, 22). An example is illustrated in Figure 5.



Notes:

Spot 1 Only

Entire Envelope:
Day Launch / Recovery

Shaded Area:
Night Launch / Recovery

Caution: Rotor downwash during landing flare may cause flight deck safety nets to bounce upright momentarily, reducing tail clearance, and possibly causing damage to aircraft or nets.

Figure 5 Sample DI Launch and Recovery Envelope.

During night operations, the U.S. Marine Corps makes it common practice to launch and recover from ships using night vision goggles (NVGs). The Marines base their use of NVGs on ambient light conditions as measured by the Light Level Calender (reference 23). The minimum light level at which the Marines no longer use NVGs is approximately 0.0022 LUX. Although the use of NVGs by the Marines indicates the acceptability of NVGs as a vision aid for shipboard operations, the U.S. Navy does not normally conduct night VFR shipboard terminal operations with NVGs.

A recent investigation of shipboard operations in degraded visual environments was conducted during the dynamic interface testing of the SH-60B LAMPS Mk III aboard the USS Cushing (DD 985) (reference 24). This investigation examined the feasibility of conducting reduced illumination helicopter night launch and recovery operations in conditions simulating wartime or emergency lighting situations. These tests were conducted under night VFR conditions, with a variety of degraded shipboard visual landing aids (VLA), and without the use of night vision devices. The evaluation further included emergency condition (EMCON) procedures, in which shipboard emissions, such as radio transmissions and guidance signals are secured.

The test results indicated that pilot workload and task difficulty are a clear inverse function of outside world visual cues and degree of aid provided by the ship. The results have strong implications with regard to on-board helicopter capabilities required for safe operation in emergency conditions. Specifically, there is an apparent need for improved displays and vision aids, as well as self contained terminal guidance systems.

Improved rotorcraft capabilities are necessary to satisfy future naval operational requirements. As an example, a recent U.S. Navy rotorcraft acquisition, the HH-60H, is representative of the future naval operation philosophy of establishing and exploiting a night/all-weather capability. The HH-60H, which can draw it's lineage from the SH-60F, was designed to perform the mission of combat search and rescue (CSAR) and special warfare support. The Navy plans to have the HH-60H's carry out CSAR in littoral missions operating off of small deck ships. Inherent in this mission is night/poor weather operational capability (reference 25). To insure adequate CSAR capability, the HH-60H is fitted with a host of mission enhancing avionics. The cockpit

instrument panel includes a 10-inch multifunctional display for display of flight and navigation information. In addition, the HH-60H is fully night vision goggle compatible. The incorporation of NVGs demonstrates the recognition of the impact that visual augmentation has on operational capabilities. Using NVGs, HH-60H units are cleared to fly below the minimum light levels set for most other military units. This allows the unit to accomplish strike-rescue missions in two ways: immediate rescue in prevailing conditions or rescue within twenty-four hours under the cover of darkness. The later relies on a "stealthy" approach rather than the use of brute firepower to suppress enemy fire.

Another example of a recent acquisition which demonstrates the impact of future naval operational requirements on the design development of rotorcraft, is that of the upgrade from the Royal Navy's primary ASW helicopter, the Lynx Mk 3, to what is to be called the Lynx Mk 8. Operated from the flight decks of most Royal Navy frigates and destroyers, the Lynx Mk 3 HAS (helicopter antisubmarine), equipped with Sea Skua ASM and antisubmarine torpedoes, extends the effective range of its parent ship's sensors and weapons while operating as an integral part of the parent ship's tactical system. The Lynx Mk 8 is simply an enhanced version of the Lynx Mk 3 (reference 26).

The Lynx Mk 8 employs an upgraded Central Tactical System (CTS) which aids navigation and the Sea Owl Passive Identification Device (PID) for day, night, poor weather surveillance and automatic target cueing and tracking. These systems reduce pilot workload and enhance mission performance.

It is important, however, to recognize here that unlike the outfitting of the HH-60H with a NVG capability, the CTS and Sea Owl, although reducing pilot workload and improving mission performance, are not UCE related. The visual cue rating (VCR) scale (Figure 2a) used in determining the UCE measures the cues for stabilization and control, not navigation or mission related divided attention tasks.

6.4 Shipboard Terminal Operations (STOPS) Procedures

Although U.S. Navy rotorcraft may have different primary and secondary missions, there remains one element of these missions, two flight phases, that are rudimentary to all U.S. Navy aircraft operations - shipboard launch and recovery.

Shipboard procedures for launch are described as follows (references 19, 27, 28 and 29). The pilot lifts the aircraft to a stable hover, performs checks on all performance indicators, and depending on ship size maneuvers the aircraft to the aft portion of the flight deck while maintaining gear mounts over the deck and again stabilizes a trimmed hover. If necessary, a pedal turn is executed to place the aircraft approximately 45 degrees off of the ships heading in the direction of the relative wind. The pilot then transitions the aircraft to forward flight by increasing collective to selected takeoff power establishing a positive vertical climb. The departure is complete when the prebriefed altitude and airspeed are attained. For IMC or night operations the helicopter typically does not deviate from the departure course until minimum altitude of approximately 300 feet is reached.

Approach conditions generally fall into three categories, day VMC, night VMC, and IMC. Further, there are three types of shipboard approaches. First, a visual glide path approach which utilizes the stabilized glide slope indicator (SGSI) on board the ship, second the standard instrument approach to minimums, and, finally, an emergency approach when the helicopter does not have adequate fuel to safely divert to an alternate airfield or aviation ship and the weather is below standard minimums. The visual and standard instrument approach are discussed below.

The visual approach glide path is used for both day and night VMC approaches as well as the visual final approach phase of the standard instrument approach in IMC. Beginning in cruise flight with an airspeed of approximately 80 knots, the pilot typically flies to intercept a 3 degree glide path from 1 to 1.2 nautical miles out at altitudes of 350 to 400 feet. Note this pattern (Figure 6) may, and is often, shortened during day/night VMC commensurate with pilot proficiency. In a general a descending, decelerating, constant glide slope angle approach is employed. The pilot routinely cross checks the visual cues from SGSI with the radar altimeter to ensure glide path control (altitude vs. range) is accurate. Rates of descent typically do not exceed approximately 500 ft/min throughout the approach.

During the day visual approach phase, the lineup is maintained using the lineup lines on the ships deck as well as visual cues from the ships structure. At night the approach line is maintained using a lighted

lineup, vertical dropline lights and any other visual cues from the ships lighting (references 22). The final approach to amphibious class ships (Figure 7) is made at a 45 degree angle to the ship centerline toward designated the landing spot on the deck. Approaches to small deck ships are flown from either directly astern (Figure 8), or at an angle, typically 30 degrees, to the landing deck on the aft end of the ship (Figure 9).

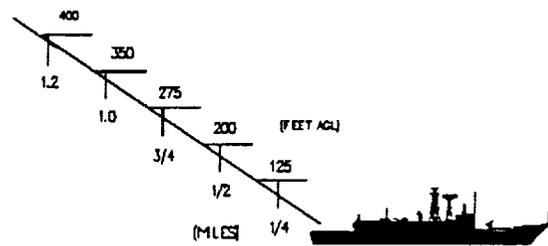


Figure 6 Typical VMC Approach path.

During the last portion of the flight phase, the pilot brings the aircraft to a stationkeeping position, depending on aircraft flying qualities and size, either just off the deck edge or over the deck for larger aircraft, waits for a lull in ship motion, transitions over the deck if necessary, and lands the aircraft. Throughout the process, the pilots are assisted by a landing signalman (LSO/LSE) who plays and advisory role, except in a wave off condition where the pilot must follow his direction.

The basic instrument approach is only utilized in a night/IFR environment. This approach is commenced from a position 2 miles astern on a heading within 30 degrees of the ships basic recovery course (BRC) at 200 feet above ground level (AGL) and 80 Knots airspeed. Upon crossing the 2 mile mark, a decent is made to 100 ft AGL, and altitude hold is then engaged. The approach is continued until visual contact is made or until a range of 1/2 mile from the ship is reached, whichever occurs first. Once visual contact is established, course and altitude are adjusted to arrive 15 ft above the flight deck. Airspeed is adjusted as required to establish a comfortable closure rate not to exceed 15 knots. The last segment of the basic instrument approach is accomplished as that of the VMC day/night approach.

In high sea states, the U.S. Navy SH-60B can be assisted in shipboard landing by a haul down system referred to as RAST (Recovery, Assist, Secure and Traverse). This recovery assist system is installed in the landing decks of certain guided missile frigates, guided missile cruisers, and destroyer class ships (reference 30).

During launch, approach and landing the pilot is not performing any additional tasks. There are no divided attention operations.

7.0 MIL-H-8501B AND STOPS

7.1 MTE / UCE / Response Type Relationship

Examining only the portion of STOPS in hover/low speed conditions, the number of specification requirements can be further reduced, as illustrated by Figures 10 and 11.

For shipboard terminal operations, several mission task elements (MTEs) can be identified. They include hovering, shipboard stationkeeping, takeoff and transition, and landing. Defining the applicable MTE/UCE/response type relationship, Tables 1(3.2) and 2(3.2) of reference 1 can be reduced to Tables 4 and 5.

To achieve Level 1 handling qualities during these MTEs, MIL-H-8501B requires at least a rate response type in pitch, roll and yaw for UCE=1. For UCE=2, required control augmentation increases to attitude command/attitude hold in pitch and roll, rate command/direction hold in yaw, and rate command/altitude hold in the vertical axis. For UCE=3, translational rate command and position hold are also required. In forward flight with degraded visual conditions, MIL-H-8501B requires rate command/attitude hold in pitch and roll and turn coordination in heading. Furthermore, in forward flight no specific response type for the vertical axis is specified. The requirements for required response types are minimums and can be upgraded if desired. If the mission and mission environment dictates the use of more than one response type, then the requirement on switching between response types, Section 3.8, also applies.

As can be seen from Table 6, many of the U.S Navy helicopters discussed earlier in Section 6.1, satisfy the requirements of MIL-H-8501B for STOPS MTEs conducted in UCEs 1 through 3. Moreover, it is

interesting to note that the aircraft which does not possess the minimum required response type for shipboard operations, in visual cue conditions resulting in UCEs > 1, is the AH-1W - a U.S Marine Corps aircraft. As discussed earlier, the Marines routinely operate in the shipboard environment with NVG's, effectively improving the UCE at night.

7.2 Sample Qualitative Requirements - Section 3 Criteria

Based on current and future operational environments, procedures and rotorcraft characteristics, a majority of the MIL-H-8501B section 3 hover/low speed criteria will apply to shipboard terminal operations. To convey the nature of these criteria, samples are presented below.

Section 3.3.2.1. Hover and Low Speed, Small Amplitude Pitch and Attitude Changes, Short Term Response to Control Inputs (Bandwidth).

The pitch response to longitudinal cockpit control force or position inputs shall meet the limits specified in Figure 12.

The small amplitude, short term response to control inputs, criteria is defined in terms of bandwidth and phase delay. These frequency domain parameters describe the system's short term transient response characteristics.

Section 3.3.3. Hover and Low Speed Moderate Amplitude Pitch Attitude Changes (Attitude Quickness).

The ratio of peak pitch rate to change in pitch attitude shall exceed the limits specified in Figure 13. The required attitude changes shall be made as rapidly as possible from one steady attitude to another without significant reversals in the sign of the cockpit control input relative to the trim position. The initial attitudes, and attitude changes required for compliance with this requirement, shall be representative of those encountered while performing the required MTEs.

The parameters that make up the moderate amplitude criteria are the ratio of the peak rate to peak attitude and the minimum change in attitude during the change from

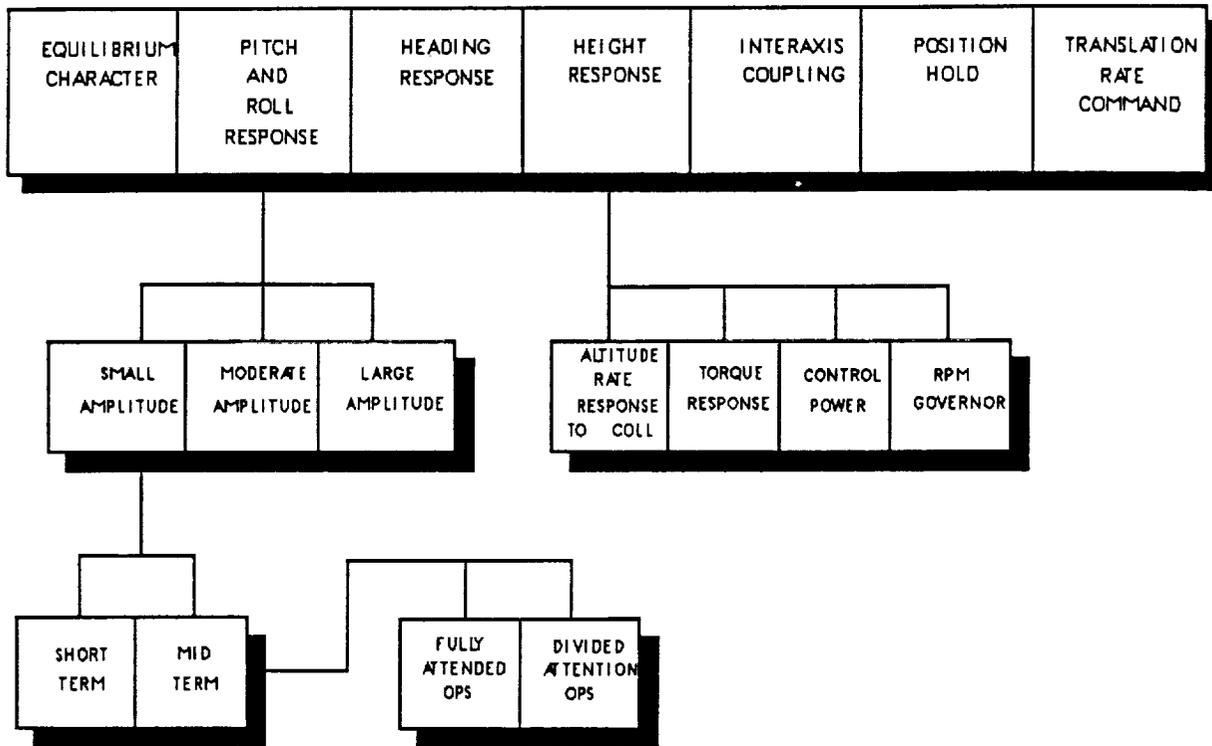


Figure 10 Specification Structure - Quantitative Requirements - Shipboard Terminal Operations.

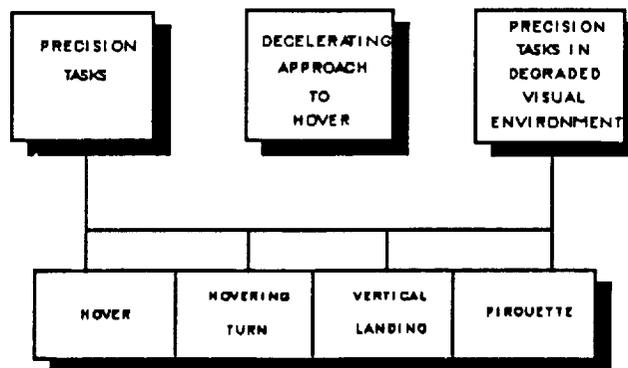


Figure 11 Specification Structure - Flight Test Requirements Relating to Shipboard Terminal Operations.

Table 4 Required Response-Type for Hover and Low Speed - Near Earth

	UCE=1		UCE=2		UCE=3	
	LV 1	LV 2	LV 1	LV 2	LV 1	LV 2
Vertical takeoff and transition to F/F - clear of earth.	Rate	Rate	Rate	Rate	Rate	Rate
Precision hover			ACAH +	Rate +	TRC +	ACAH +
Shipboard landing including RAST			RCDH +	RCDH	RCDH +	RCDH +
Vertical takeoff and Transition to near earth flight			RCHH		RCHH +	RCHH
Hover Taxi/NOE Traveling					PH	
Precision Vertical Landing			ACAH +			ACAH +
			RCDH			RCDH

Notes:

1. A requirement for RCHH may be deleted if the Vertical Translational Rate Visual Cue Rating is 2 or better, and divided attention operation is not required. If RCHH is not specified, an Altitude-Rate Response Type is required (See Paragraph 3.2.9, reference 1).
2. Turn Coordination (TC) is always required as an available Response-Type for the slalom MTE in the Low Speed flight range as defined by Paragraph 2.6.2. However, TC is not required at airspeeds less than 15 knots.
3. For UCE =1, a specified Response-Type may be replaced with a higher rank of stabilization, providing that the moderate and Large Amplitude Attitude Change requirements are satisfied.
4. For UCE=2 or 3, a specified Response-Type may be replaced with a higher rank of stabilization.
5. The rank-ordering of combinations of Response-Type from least to most Stabilization is defined as:
 1. Rate
 2. ACAH+RCDH
 3. ACAH+RCDH+RCHH
 4. Rate+RCDH+RCHH+PH
 5. ACAH+RCDH+RCHH+PH
 6. TRC+RCDH+RCHH+PH

Rate => Rate or Rate Command Attitude Hold (RCAH) Response-Type (Paragraph 3.2.5 and 3.2.6, reference 1).

TC => Turn Coordination (Paragraph 3.2.10.1, reference 1)

ACAH => Attitude Command Attitude Hold Response-Type (Paragraph 3.2.6 and 3.2.7, reference 1).

RCHH => Vertical-Rate Command with Altitude (Height) Hold Response-Type (Paragraph 3.2.9.1, reference 1).

RCDH => Rate-Command with Heading (Direction) Hold Response-Type (Paragraph 3.2.5 and 3.2.6, reference 1).

PH => Position Hold Response-Type (Paragraph 3.3.11, reference 1)

TRC => Translational-Rate-Command Response-Type (Paragraph 3.2.8, reference 1)

Table 5 Required Response-Types in Forward Flight

Pitch and Roll Attitude	
Rate	Pitch - Rate or Attitude, Attitude Hold Required (RCAH or ACAH) Roll - Rate with Attitude Hold (RCAH)
VMC cruise/climb/decent	IMC cruise/climb/decent IMC departure IMC approach (constant speed) IMC decelerating approach (3-cue director required)
Heading -- All require Turn Coordination (see Paragraph 3.4.6.2)	
Height -- No specific Response-Type (see Paragraph 3.4.3)	

Table 6 Response Type of Current Fleet Helicopters

A/C	Pitch	Roll	Yaw	Heave	Other Modes
MH-53E	ACAH	ACAH	RCDH	RCHH	BARALT/RADALT Hold Cable Tension/Skew Hold Crew Hover (TRC) Hover Coupler (PH) Airspeed Hold (>60 Kts)
AH-1W	RC	RC	RC	RC	
SH-3G/H	ACAH	ACAH	RCDH	RCHH*	TRC W/Doppler Cable Angle Hold Crew Hover (TRC) Auto Depart/Approach
CH-46E (SR+M)	ACAH	ACAH	RCDH	RCHH*	
SH-2G/F	ACAH	ACAH	RCDH	RCHH*	TRC W/Doppler
SH-60B	ACAH	ACAH	RCDH	RCHH*	Hover Coupler Ground Speed Command/Hol

* Altitude Hold Pilot Selectable

Note: In all cases, Attitude Command authority is limited to 10-15% of control movement due to series actuation limits.

Table 7 MIL-H-8501B Requirements for Large Amplitude Attitude Changes with regard to Maneuvering Associated with Shipboard Operations

MISSION-TASK-ELEMENT	RATE RESPONSE-TYPES						ATTITUDE RESPONSE-TYPES			
	MINIMUM ACHIEVABLE ANGULAR RATE (DEG/SEC)						MINIMUM ACHIEVABLE ANGLE (DEG)			
	LEVEL I			LEVEL II+III			LEVEL I		LVLII+III	
	Q	P	R	Q	P	R	θ	φ	θ	φ
LIMITED MANEUVERING All MTEs not otherwise specified	± 6	± 21	±9.5	±3	± 15	±5	±15	±15	±7	±10
MODERATE MANEUVERING Rapid Transition to Hover Slope Landing Shipboard Landing	±13	± 50	±22	±6	± 21	+9.5 - 30	± 20	±60	±13	±30

one steady attitude to another. This requirement is a measure of the agility, or attitude quickness, of the system. Use of the peak rate/peak attitude ratio is based, in part, on the concept that for an ideal system, this ratio can be analytically related to the system bandwidth. Using this relationship, the lower end of the moderate amplitude requirement is anchored at the equivalent small amplitude requirements. Similarly, the upper boundary is anchored at the equivalent value of the large amplitude requirements.

Section 3.3.4. Hover and Low Speed, Large Amplitude Pitch Attitude Changes (Control Power).

The minimum achievable angular rate shall be no less than the values specified in Table 7. The specified rate must be achieved in each axis while limiting excursions in the other axis with the appropriate control inputs.

The large amplitude criteria is defined in terms of the maximum achievable rates or attitudes. As such, this criteria is a measure of the vehicle's control power.

Section 3.3.10.1 Height Response Characteristics.

The vertical rate response shall have a qualitative first-order appearance for at least 5 seconds following a step collective input. The limits on the parameters defined by the following equivalent first-order vertical rate to collective transfer function are given in Table 8.

Table 8 Maximum Values for Height Response to Collective Controller

LEVEL	$T_{h_{eq}}$ (sec)	$\tau_{h_{eq}}$ (sec)
I	5.0	0.20
II		0.30

$$\frac{\dot{h}}{\delta_c} = \frac{k e^{-\tau_{h_{eq}} s}}{T_{h_{eq}} s + 1}$$

The equivalent system parameters are to be obtained using the time domain fitting method defined in Figure 8(3.3) of reference

1. The coefficients of determination, r^2 shall be greater than 0.97 and less than 1.03 for compliance with this requirement.

The height response criteria is defined in terms of rise time and delay. Not unlike the bandwidth parameter in the frequency domain, rise time is a measure, in the time domain, of how rapidly the systems responds. Time delay simply measures how long the heave response lags the collective

Section 3.3.10.3 Vertical Axis Control Power.

While maintaining a spot hover with the wind from the most critical direction at a velocity of up to 35 knots, and with the most critical loading and altitude, it shall be possible to produce the vertical rates specified in Table 9, 1.5 seconds after initiation of a rapid displacement of the vertical axis controller from trim. Applicable engine and transmission limits shall not be exceeded.

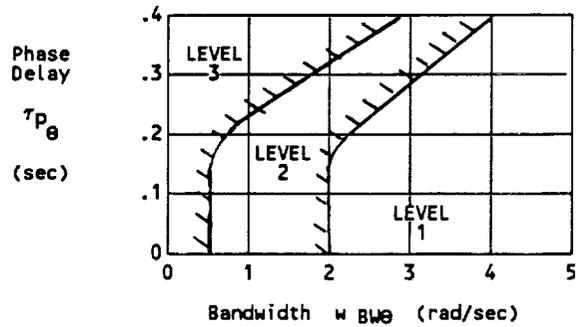
Table 9 Vertical Axis Control Power

LEVEL	Achievable Vertical Rate in 1.5 Seconds m/s (ft/min)
I	0.81 (160)
II	0.28 (55)
III	0.20 (40)

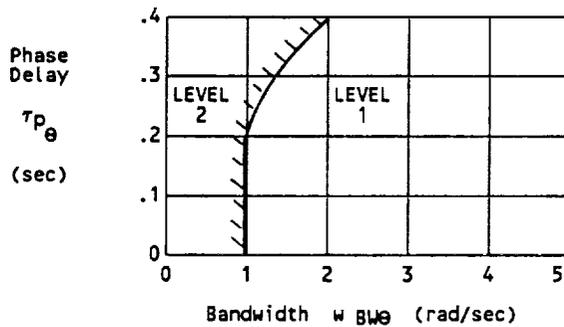
An example evaluation of selected specification requirements utilizing the predicted and actual handling qualities of a naval rotorcraft may be found in reference 31.

8.0 GENERAL DESIGN IMPLICATIONS AND OPERATIONAL CAPABILITY

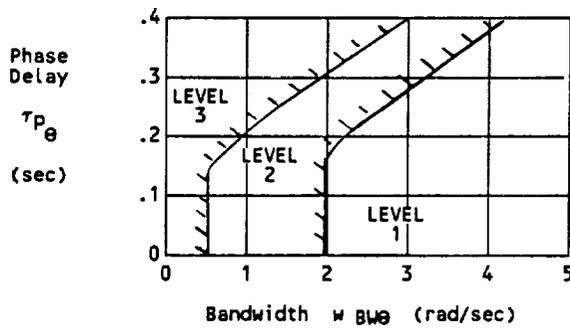
Application of MIL-H-8501B has vast design implications. These implications are driven by the MIL-H-8501B philosophy that the rotorcraft should be viewed as a whole system and not a collection of individual isolated systems. As such, MIL-H-8501B is designed to ensure the pilot is provided with a total system yielding superior flying qualities and allowing him to effectively and safely perform his mission. In this regard, MIL-H-8501B criteria will influence the design of every major aircraft component from the



a) Target Acquisition and Tracking



b) All Other MTEs - UCE = 1 and Fully Attended Operations



c) All Other MTEs - UCE > 1 and/or Divided Attention Operations

Figure 12 Requirements for Small Amplitude Pitch Attitude Changes, Hover and Low Speed, STOP MTEs, and fully attended operations.

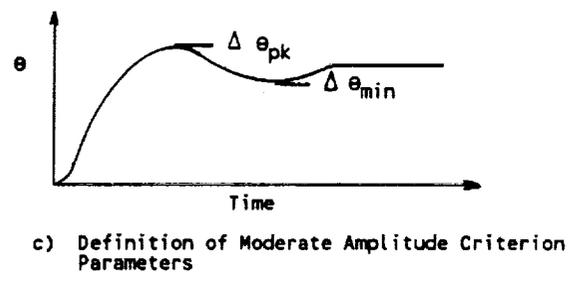
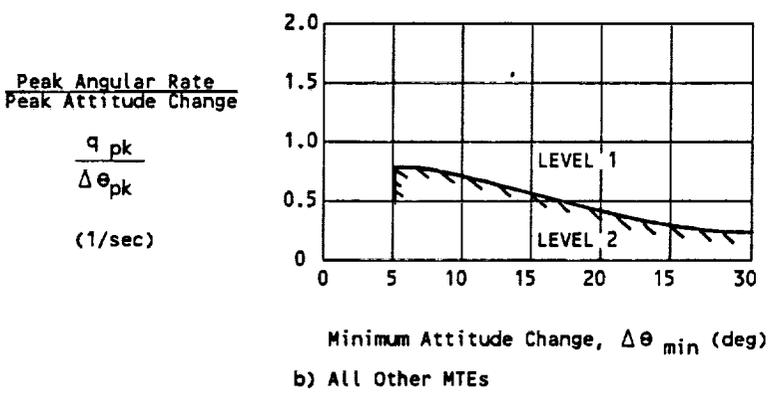
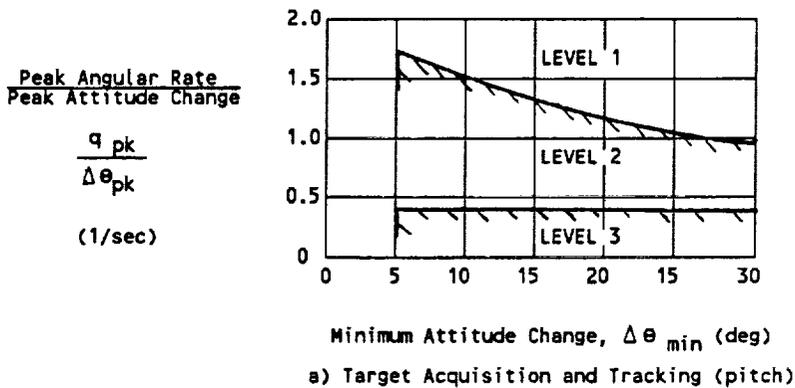


Figure 13 Requirements for Moderate Amplitude Pitch Attitude Changes, Hover and Low Speed, STOP MTEs, and Fully Attended Operations.

airframe and rotor to flight controls, displays, and vision aids.

The explicit relationship between the vehicle's dynamics, UCE and resultant flying qualities as defined in MIL-H-8501B, will force the designer to consider the displays and vision aids on an equal footing with the flight control system. For example, the reliability or redundancy of all flight control and avionics system components, that impact the vehicles dynamics as well as the UCE, must be considered. These components include, but are not limited to: gyros, flight control computers, mission computers, display processors, sensors, actuators, and display units. Furthermore, the dynamic response criteria will directly impact actuator, hub, blade, airframe, and flight control law design.

Both the philosophy of and the criteria specified in MIL-H-8501B are mission oriented. The philosophy is founded on a systems approach and involves a partitioning of criteria according to the fundamental characteristics necessary to satisfactorily perform the defined mission task elements. The dynamic response criteria have been derived from experimentation utilizing mission related evaluation tasks. As a result, compliance with MIL-H-8501B should insure flying qualities will not detract from an adequate operational capability. Likewise, non-compliance will most likely result in increased pilot workload and/or a reduction in operational capability.

9.0 CONCLUDING REMARKS

A complete understanding of the philosophy, structure, methodology, and application of the proposed U.S. military specification for Handling Qualities Requirements for Military Rotorcraft, MIL-H-8501B (reference 1), is a requisite for the proper specification of flying qualities design requirements. Proper selection of the flying qualities design requirements is critical to proper helicopter design and, in turn satisfactory operation. Satisfactory operation of all new helicopters, tiltrotors and V/STOLS, in the shipboard environment as well as all other mission environments, is critical to the U.S. Navy.

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